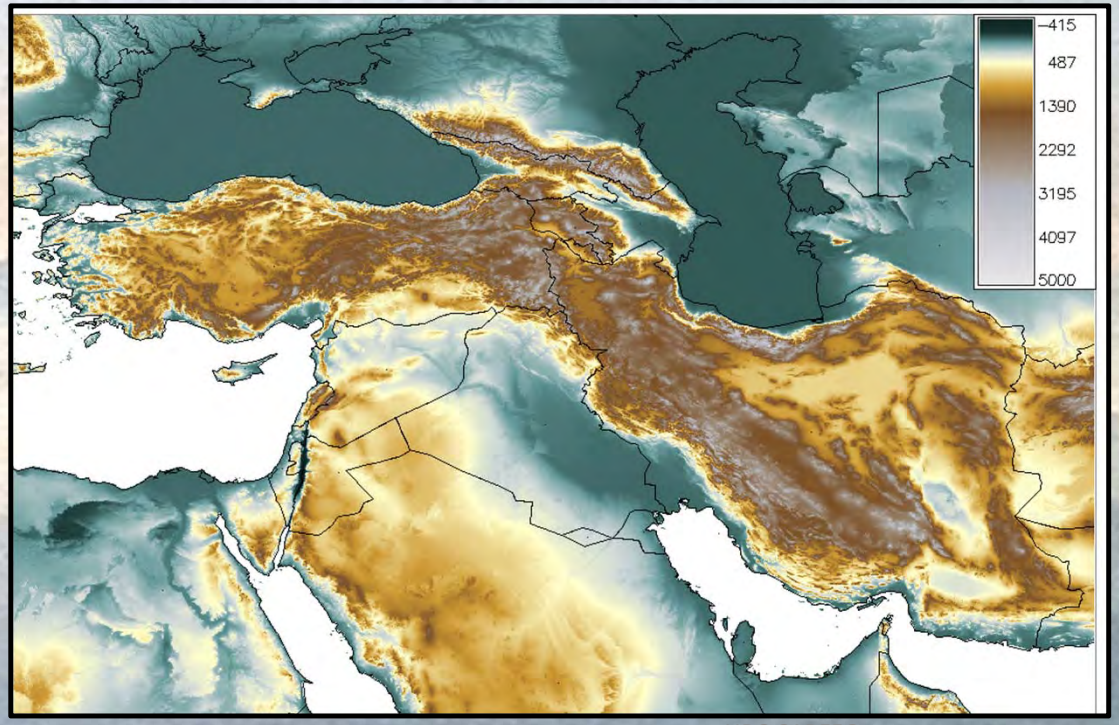
Precipitation, Soil Moisture, Snow, and Flash Flood Guidance Components

HYDROLOGIC RESEARCH CENTER

6 May 2015

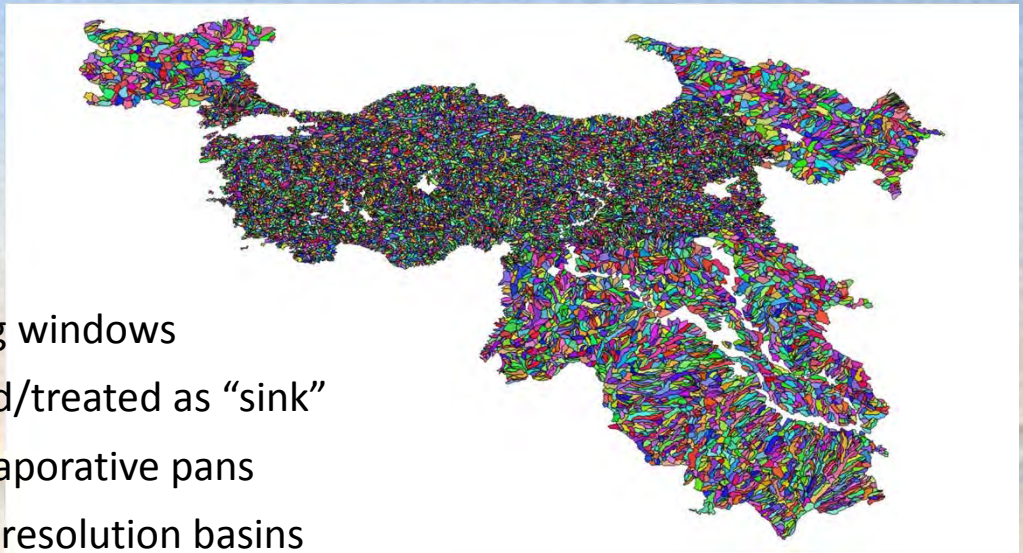
Flash Flood Basin Delineation

GIS processing of digital elevation data to delineate small flash flood watershed areas and determine basins characteristics (A, L, S)



- SRTM 90-m DEM
- GRASS GIS software
- Minimum headwater stream size threshold defines basin size: targeted average area of ~150km^2

BSMEFFG Basin Delineation

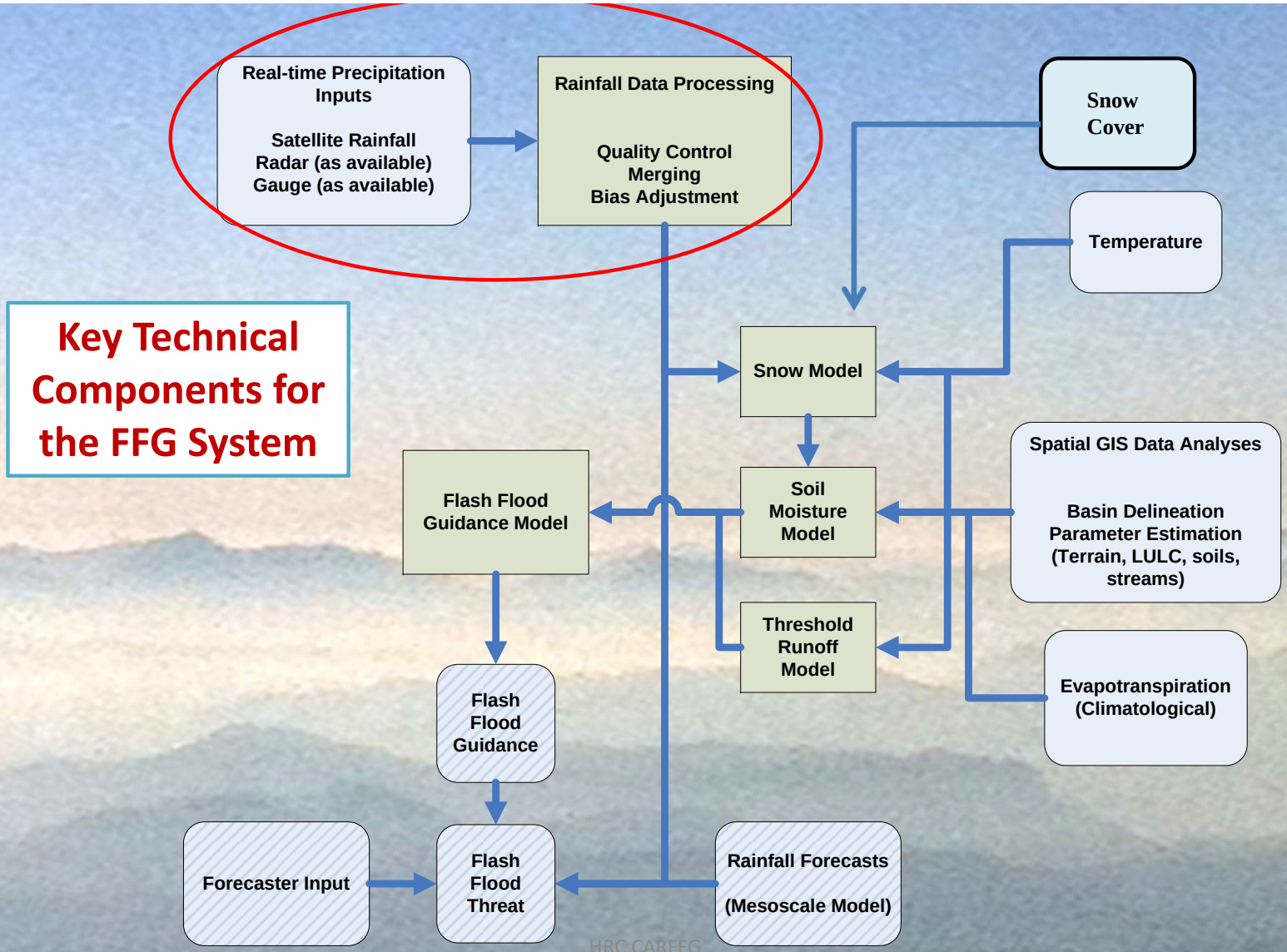


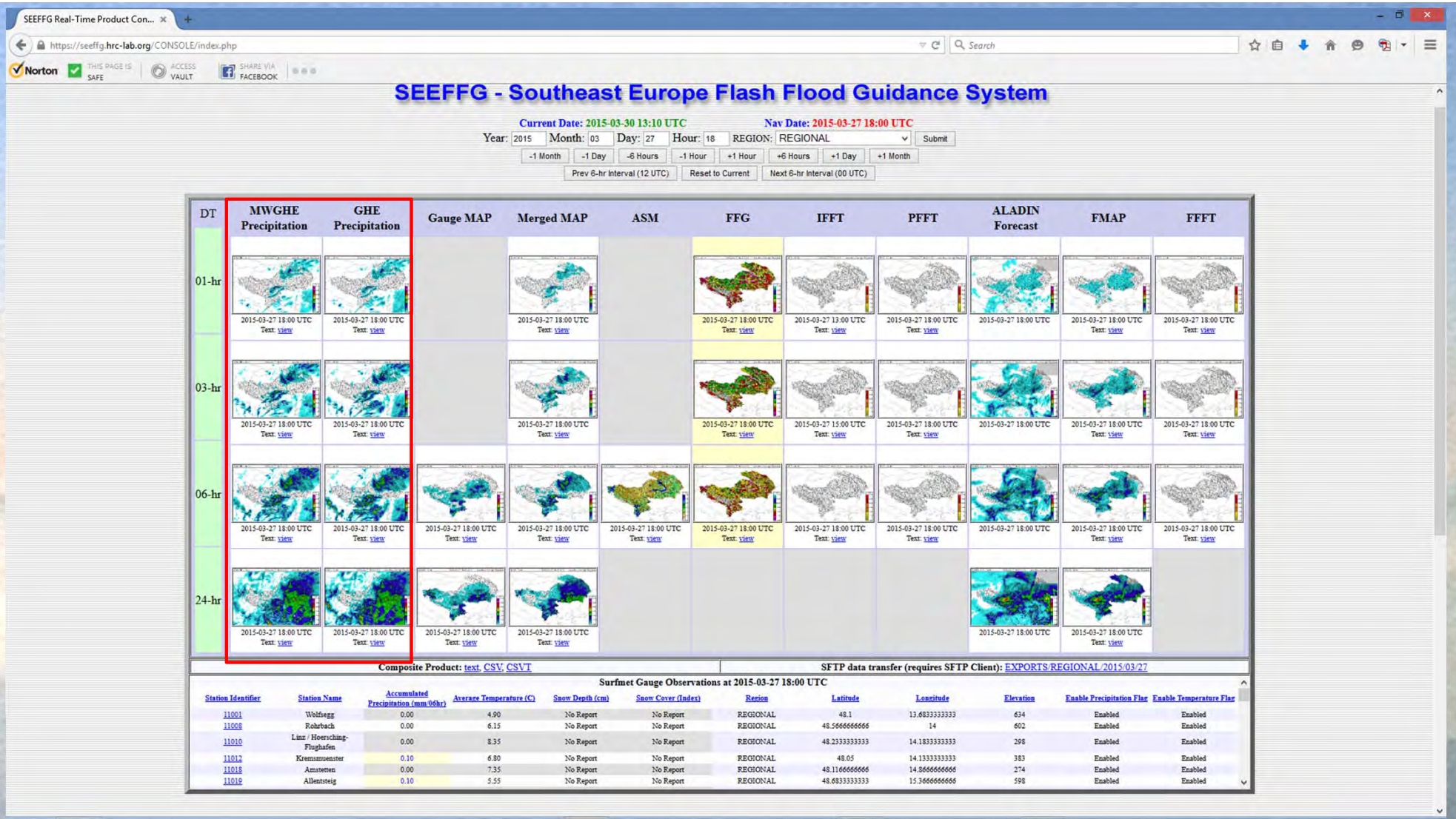
- Multiple processing windows
- Large rivers omitted/treated as “sink”
- Major lakes and evaporative pans
- Statistics with high resolution basins
  - A total of nearly 16,000 basins
  - A total of nearly 11,000 basins in Turkey
  - Average subcatchment basin area:

    ~= 250 km^2 (outside of Turkey)

    ~= 65 km^2 (inside of Turkey)

Key Technical Components for the FFG System

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https://seeffg.hrc-lab.org/CONSOLE/index.php
SEEFFG - Southeast Europe Flash Flood Guidance System
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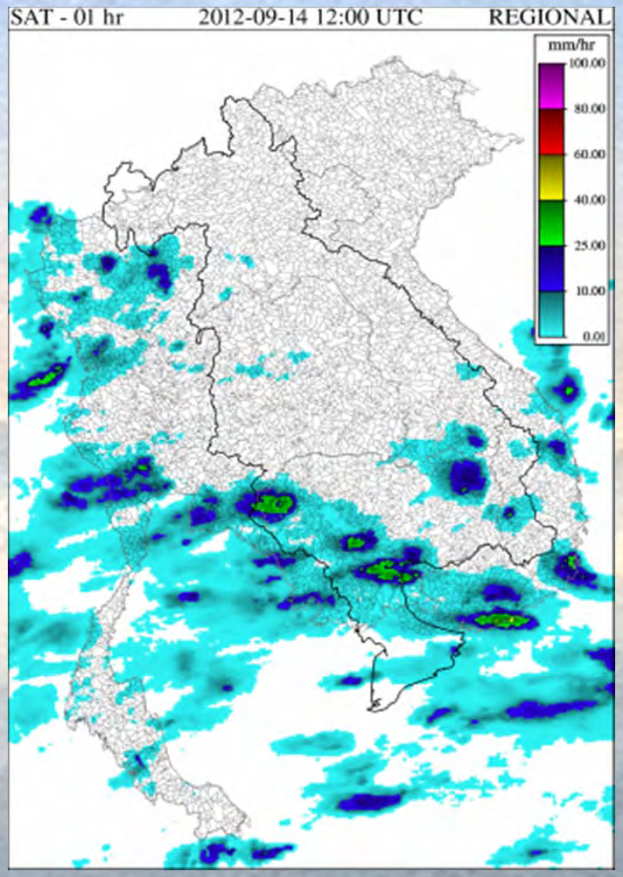
Nav Date: 2015-03-27 18:00 UTC
Year: 2015 Month: 03 Day: 27 Hour: 18 REGION: REGIONAL Submit
-1 Month -1 Day -6 Hours -1 Hour +1 Hour +6 Hours +1 Day +1 Month
Prev 6-hr Interval (12 UTC) Reset to Current Next 6-hr Interval (00 UTC)
DT
MWGHE Precipitation
GHE Precipitation
Gauge MAP
Merged MAP
ASM
FFG
IFFT
PFFT
ALADIN Forecast
FMAP
FFFT
01-hr
03-hr
06-hr
24-hr
Composite Product: text, CSV, CSVT
SFTP data transfer (requires SFTP Client): EXPORTS/REGIONAL/2015/03/27
Surfmet Gauge Observations at 2015-03-27 18:00 UTC
Station Identifier
Station Name
Accumulated Precipitation (mm/06hr)
Average Temperature (C)
Snow Depth (cm)
Snow Cover (Index)
Region
Latitude
Longitude
Elevation
Enable Precipitation Flag
Enable Temperature Flag
11001 Wolfsegg 0.00 4.90 No Report No Report REGIONAL 48.1 13.6833333333 634 Enabled Enabled
11008 Rohrbach 0.00 6.15 No Report No Report REGIONAL 48.5666666666 14 602 Enabled Enabled
11010 Linz / Hoersching-Flughafen 0.00 8.35 No Report No Report REGIONAL 48.2333333333 14.1833333333 298 Enabled Enabled
11012 Kremsmuenster 0.10 6.80 No Report No Report REGIONAL 48.05 14.1333333333 383 Enabled Enabled
11018 Amstetten 0.00 7.35 No Report No Report REGIONAL 48.1166666666 14.8666666666 274 Enabled Enabled
11019 Allentsteig 0.10 5.55 No Report No Report REGIONAL 48.6833333333 15.3666666666 598 Enabled Enabled

Satellite Rainfall - Hydroestimator



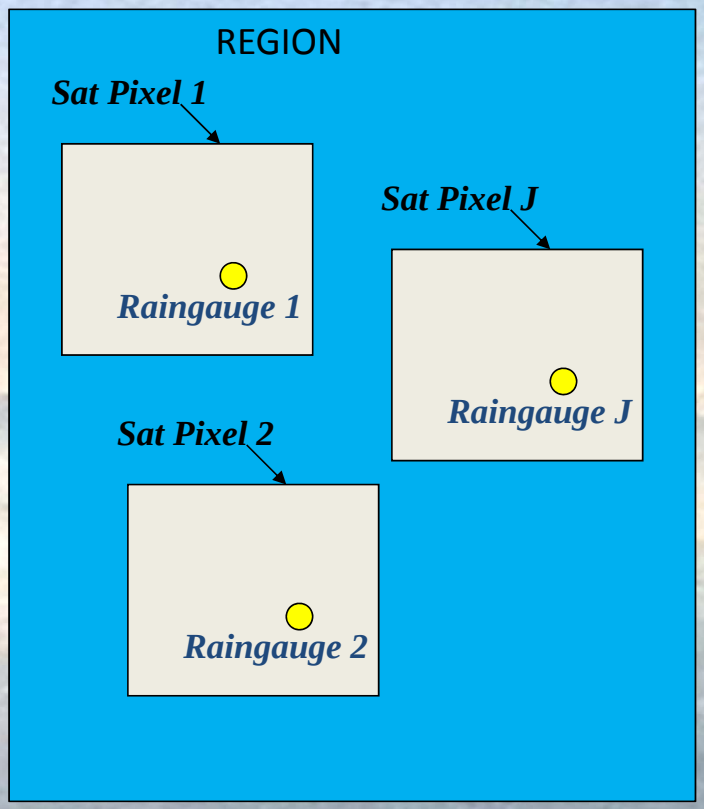
- **IR based (10.7 μm)**
- **Short latency**

Rain Rate =
Function of brightness temperature

Enhanced for:

1. Atmospheric moisture effects
2. Orography (upslope/downslope)
3. Convective Eqlb. Level (warm-top convection)
4. Local pixel T difference with surroundings
5. Convective core/no-core region

Bias and Log-Bias Factors



$$\beta_t = \ell n \left[\frac{\sum_{j=1}^{N_g} R_g(t, j)}{\sum_{j=1}^{N_g} R_s(t, j)} \right]$$

Log-Bias

Bias (B)

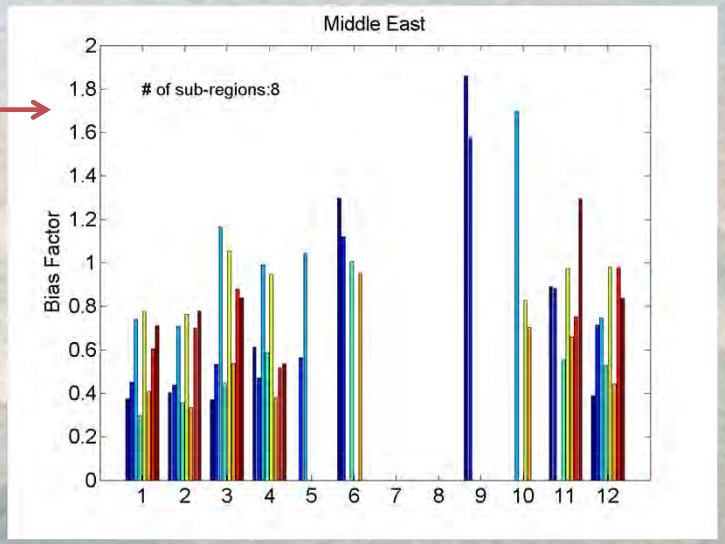
Climatological Adjustment Using Gauges and Corresponding Satellite Pixel Data

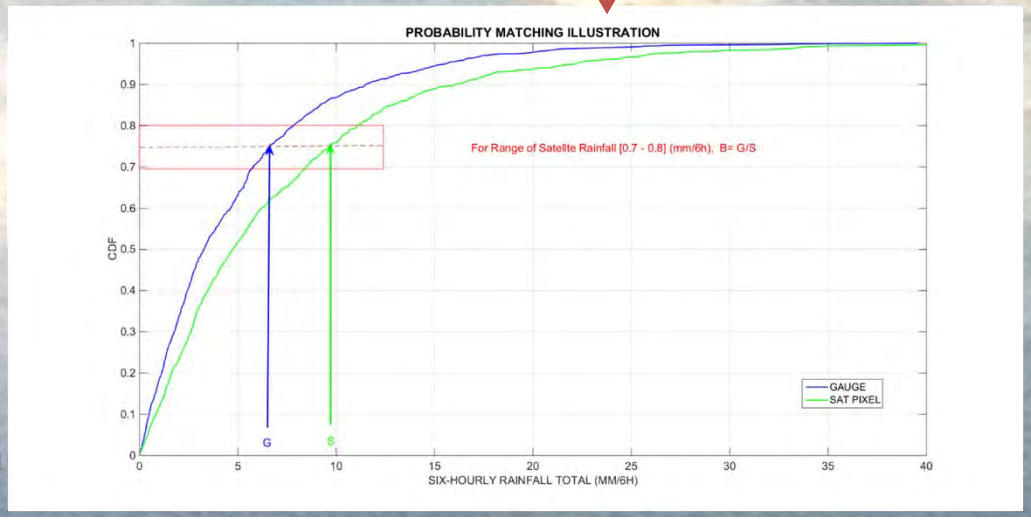
- Historical Data for regions of uniform hydroclimatology, terrain and gauge density
- Usually done for an given month or season
- Result is bias factor for each region and month/season

Bias Factor computed from:

(1) Mean values

(2) Probability matching considerations





Dynamic Bias Adjustment Basics

$$\beta_t = \ell n \left[\frac{\sum_{j=1}^{N_g} R_g(t,j)}{\sum_{j=1}^{N_g} R_s(t,j)} \right]$$

$$\beta_{t+1} = \beta_t + w_{t+1}$$

$$z_{t+1} = \beta_{t+1} + v_{t+1}$$

Kalman Filter
Stochastic Approximations

- N pairs of consecutive values
- At least 20% raingauges with rain
- Conditional Mean > Threshold (mm/h) (satellite/radar and gauge)

Bias (B)

Important issue:
Gauge data quality control

Multi-Spectral Satellite Rainfall

HE

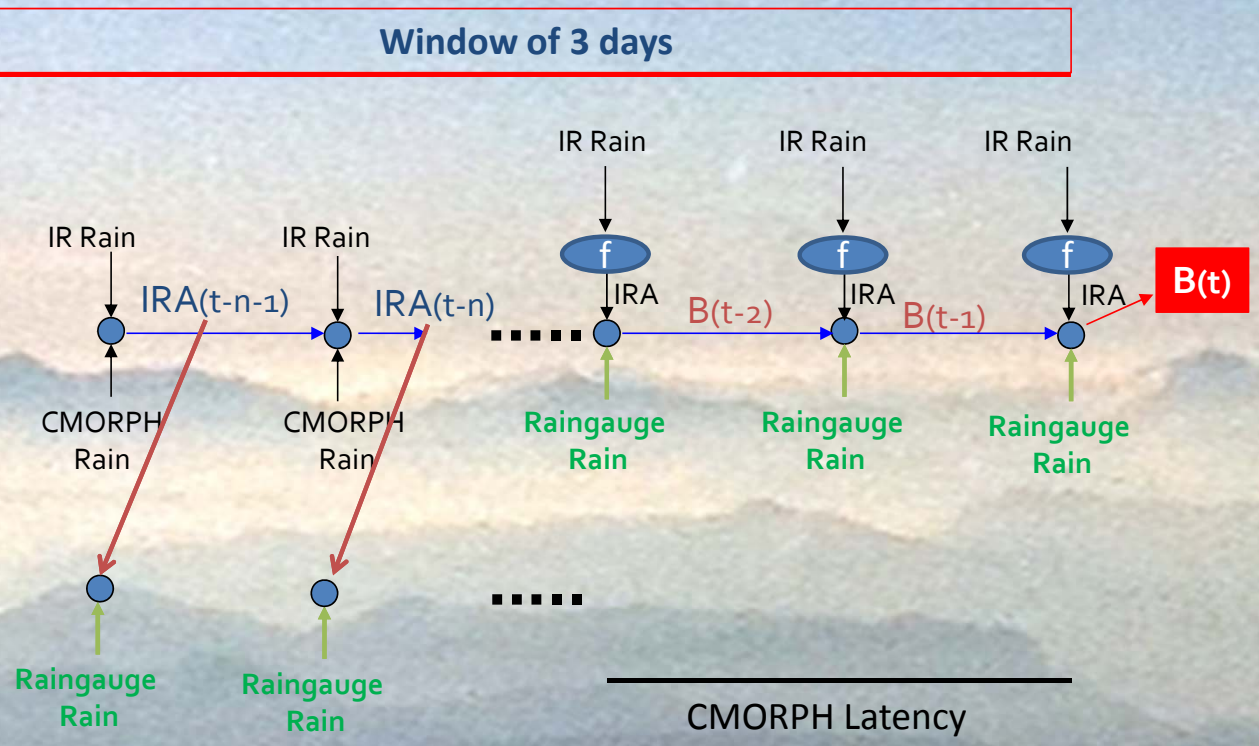
IR – Based
30-min latency in operations
Based on measurements of top cloud brightness temperature

CMORPH

MW – Based
18-26 hour latency in operations
Based on measurements of microwave scattering from raindrops

New global FFGS product combines IR-based HE rainfall with MW-based CMORPH rainfall

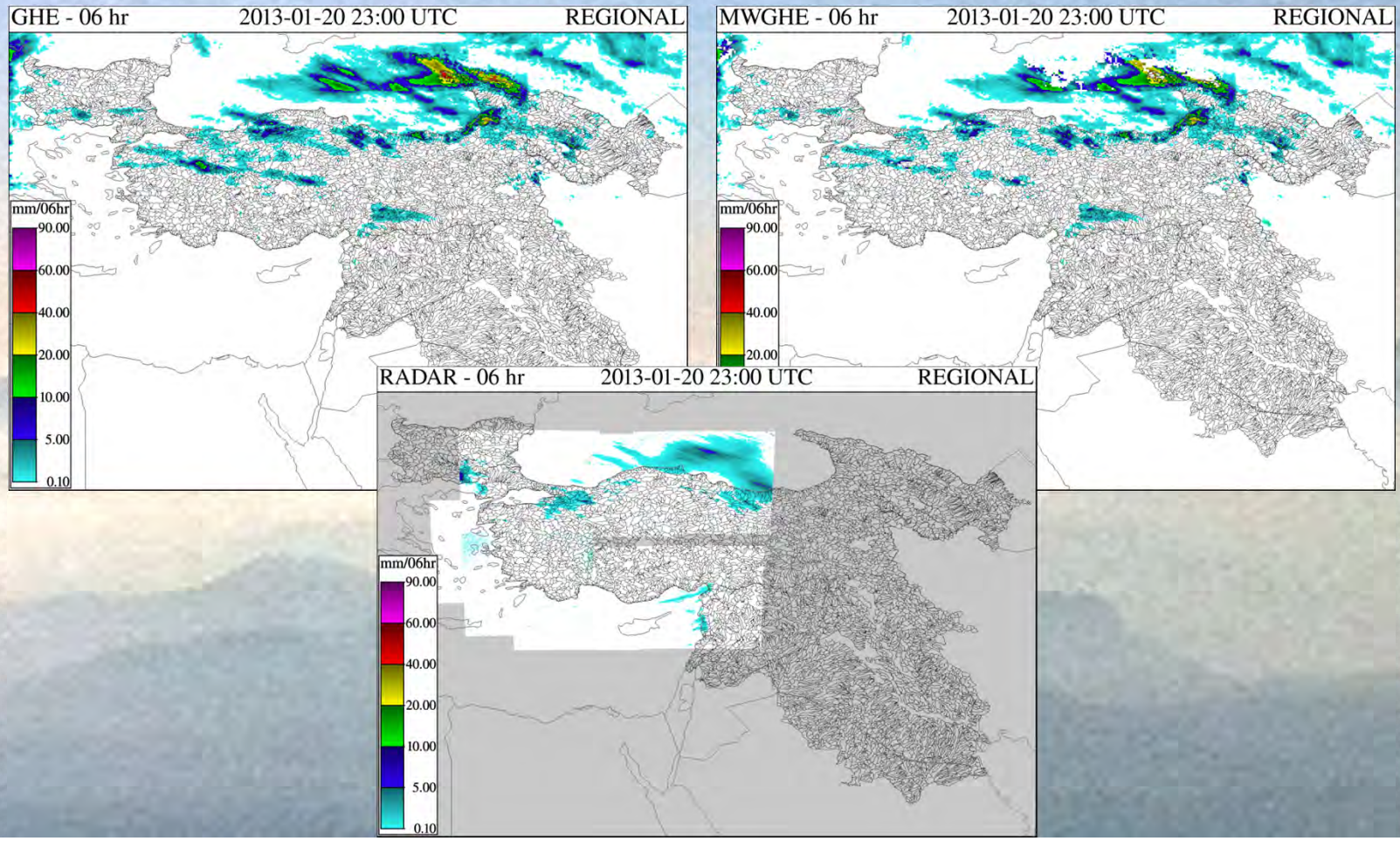
Multi-Spectral Satellite Rainfall for FFG Systems



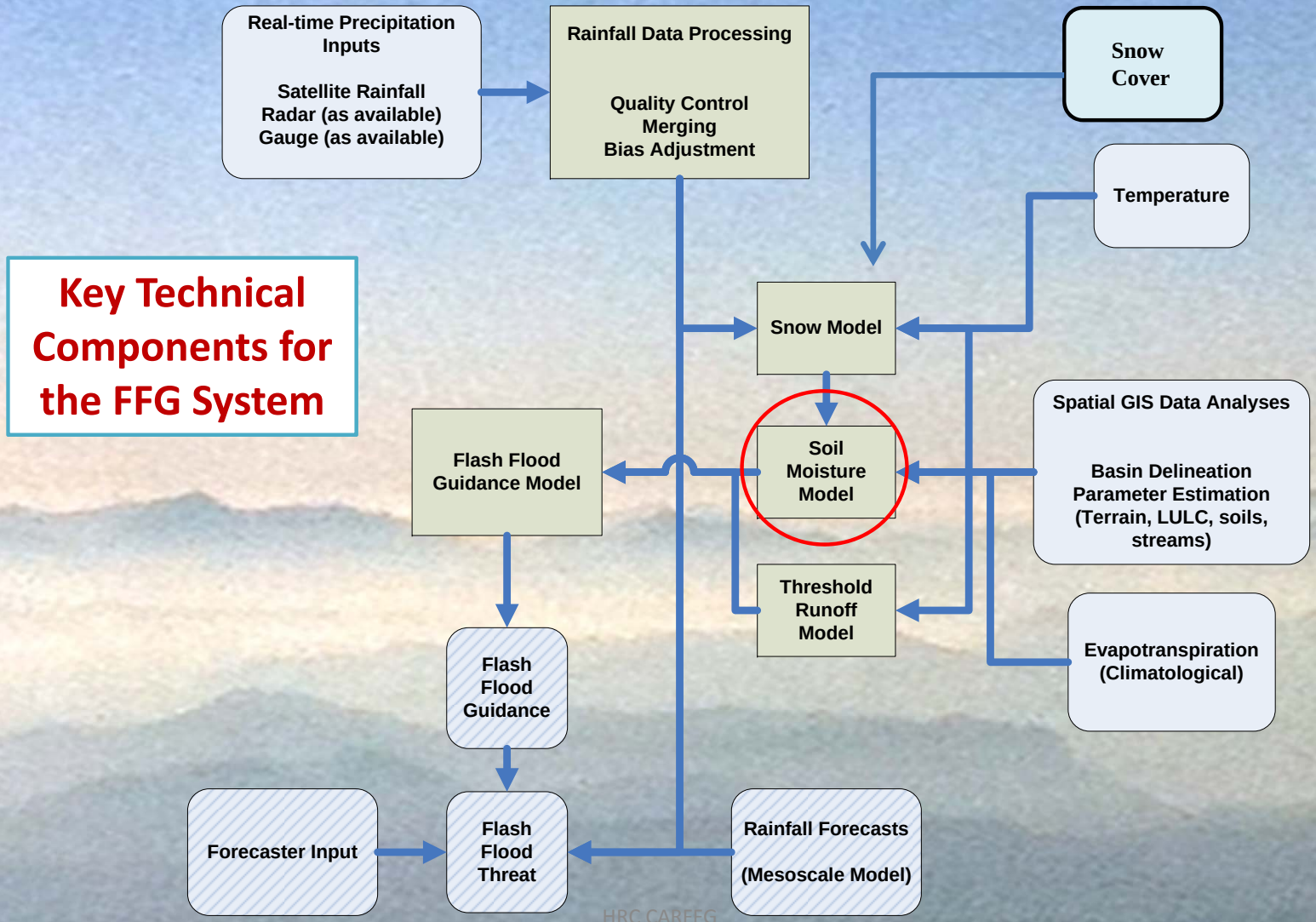
Examples from BSMEFFG

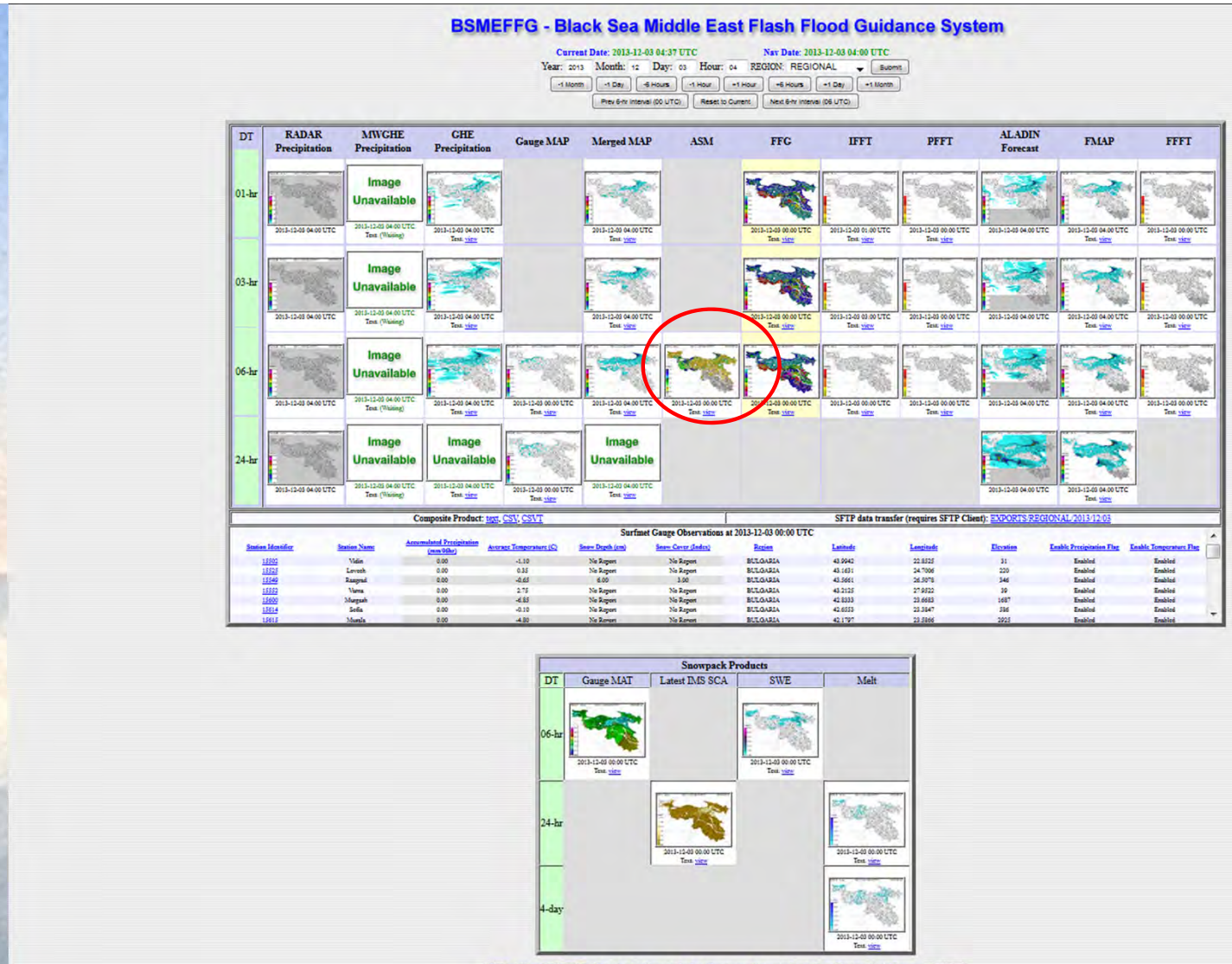
Original GHE

Adjusted GHE



Key Technical Components for the FFG System




BSMEFFG - Black Sea Middle East Flash Flood Guidance System
Current Date: 2013-12-03 04:37 UTC
Nav Date: 2013-12-03 04:00 UTC
Year: 2013 Month: 12 Day: 03 Hour: 04 REGION: REGIONAL Submit
-1 Month -1 Day -6 Hours -1 Hour +1 Hour +6 Hours +1 Day +1 Month
Prev 6-hr interval (00 UTC) Reset to Current Next 6-hr interval (06 UTC)
DT
RADAR Precipitation
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GHE Precipitation
Gauge MAP
Merged MAP
ASM
FFG
IFFT
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ALADIN Forecast
FMAP
FFFT
01-hr
03-hr
06-hr
24-hr
Image Unavailable
Composite Product: text, CSV, CSVT
SFTP data transfer (requires SFTP Client): EXPORTS/REGIONAL/2013/12/03
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Station Identifier
Station Name
Accumulated Precipitation (mm/06hr)
Average Temperature (C)
Snow Depth (cm)
Snow Cover (Index)
Region
Latitude
Longitude
Elevation
Enable Precipitation Flag
Enable Temperature Flag
Snowpack Products
Gauge MAT
Latest IMS SCA
SWE
Melt
4-day
HOME | About BSMEFFG Real-Time Product Console | Product Descriptions | Processing Logs | Server Monitor | Static Resources | Dashboard
BSMEFFG Real-Time Product Console v 1.0, Release Date: June 2013
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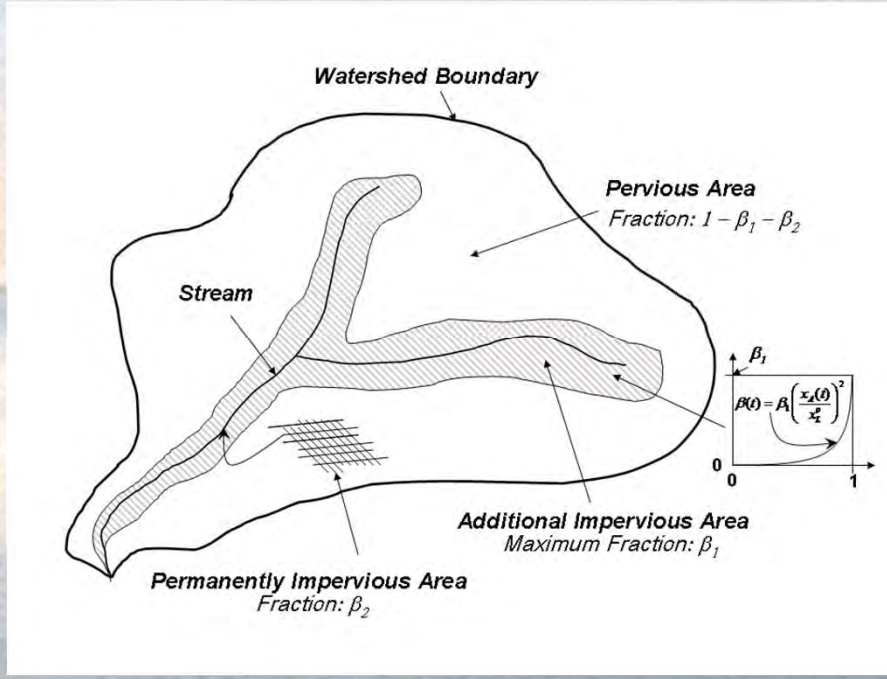
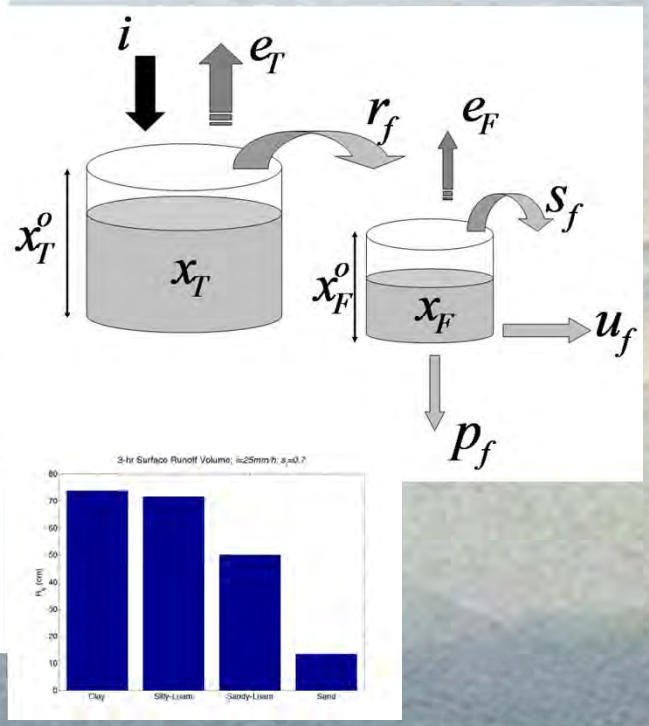
Soil Water Index Model: Combined Runoff - Sacramento Model Adaptation

Soil water index model:

- Saturation excess runoff
- Infiltration excess runoff
- Combined runoff

Soil Water: Depth Integrated Soil Moisture

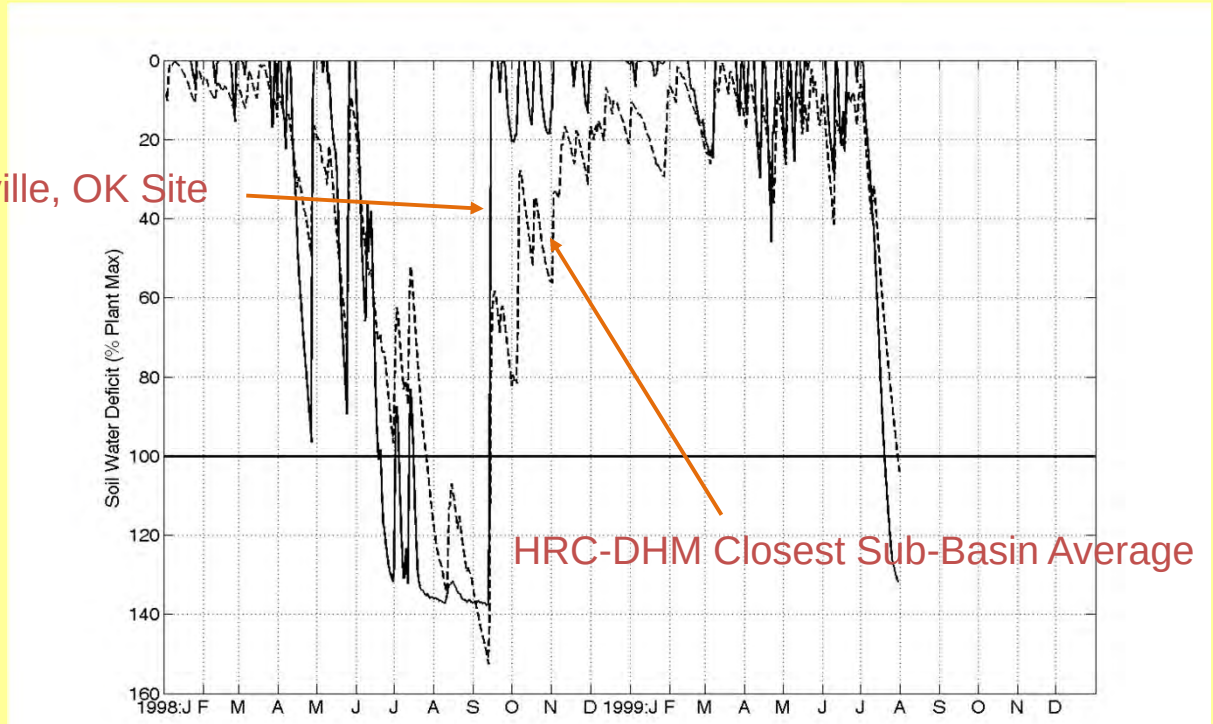




On Site Soil Water Deficit Validation

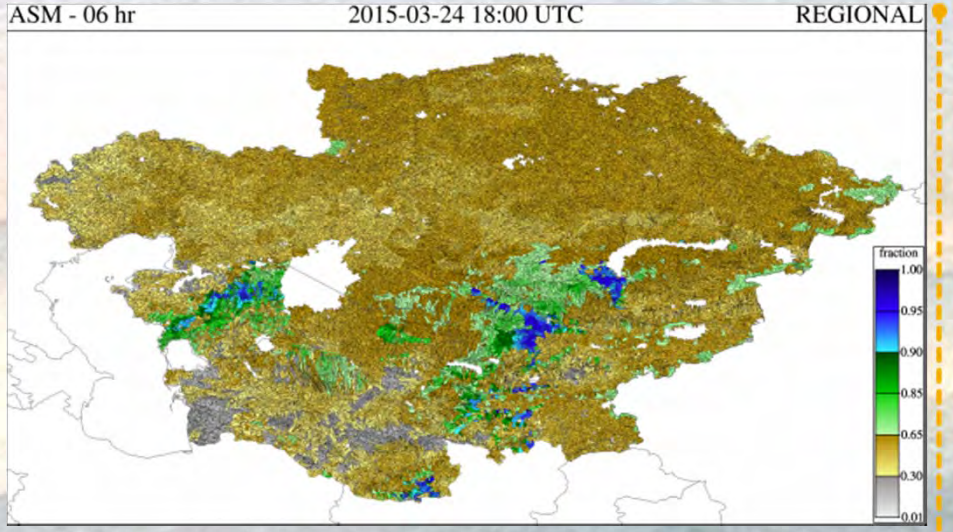
Illinois River (Semi-Arid US)

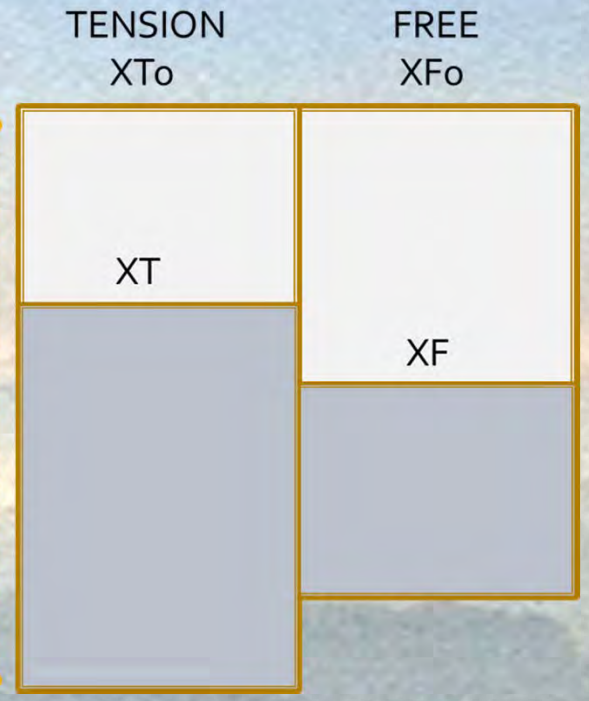
Westville, OK Site



Reasonably good reproduction of depth-integrated soil water deficit

Average Soil Moisture (Water)

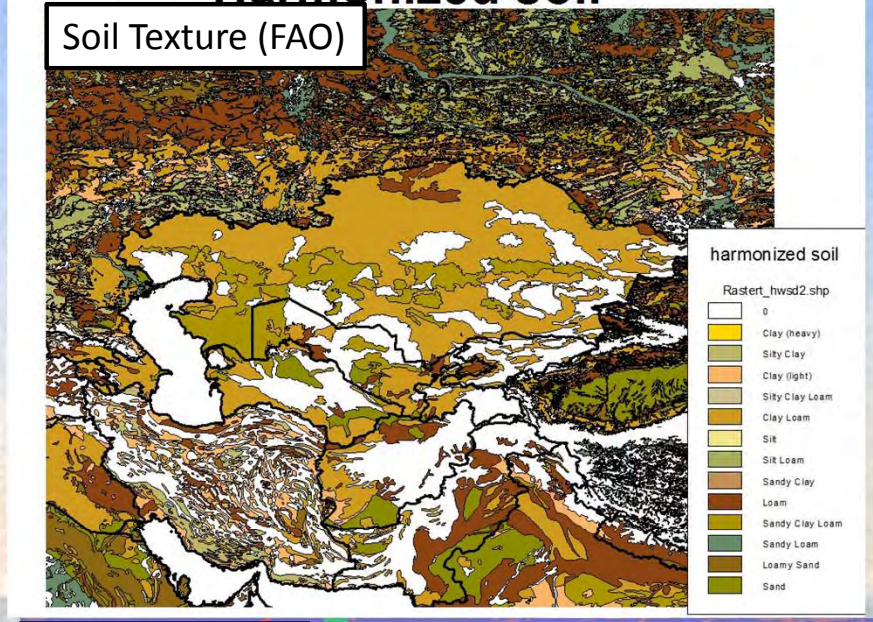




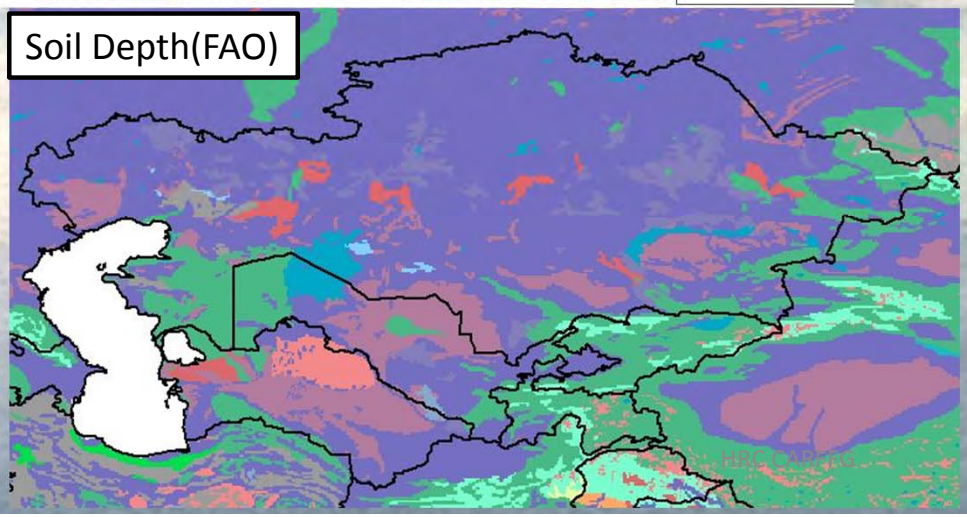
ASM = (XT + XF) / (XTo + XFo)

Harmonized soil

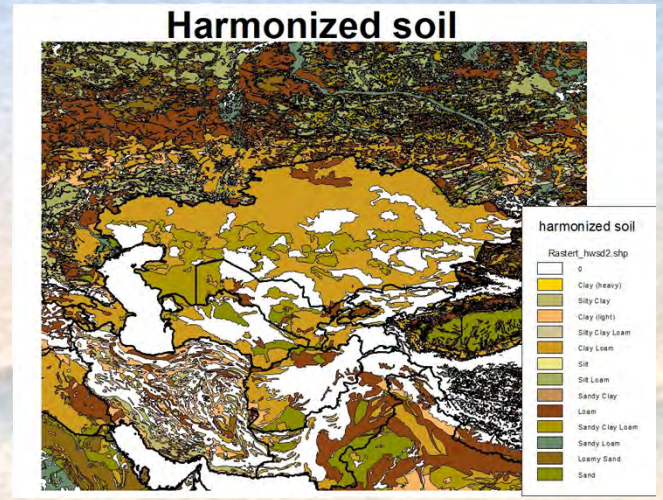
Soil Texture (FAO)

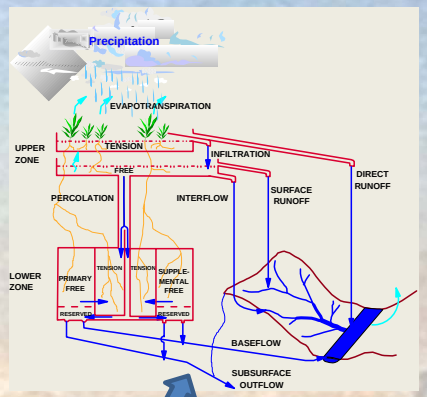


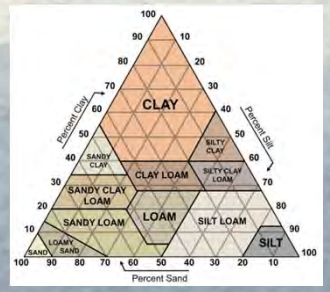
Soil Depth(FAO)



A priori parameter estimation



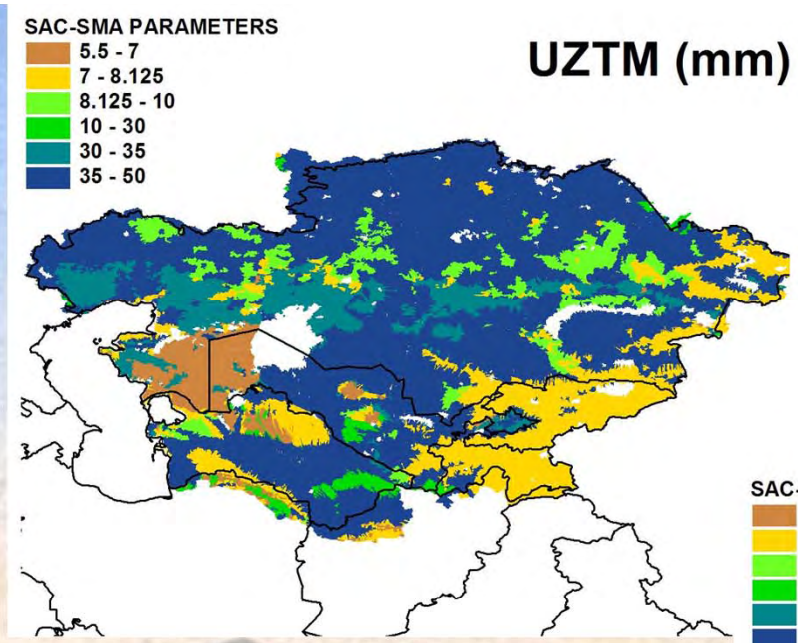


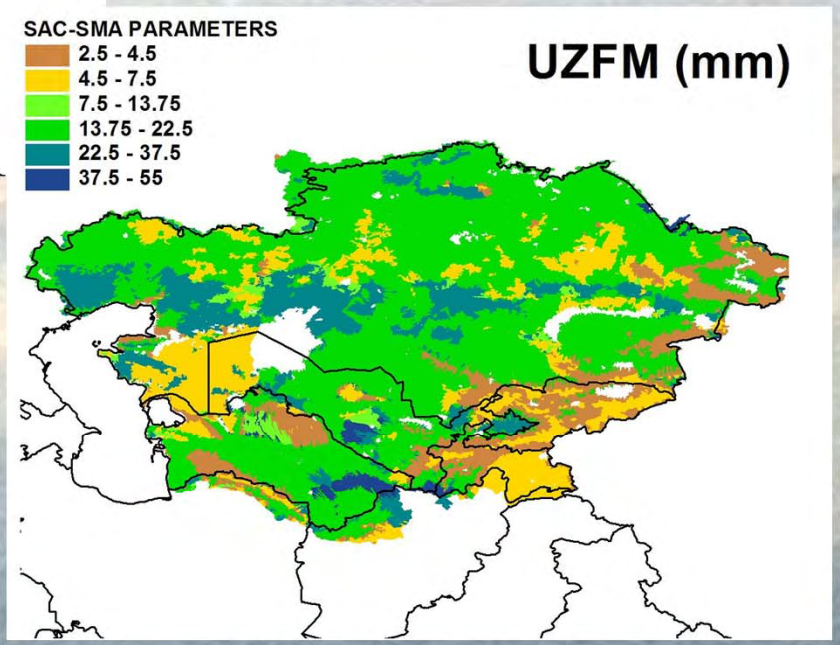


Soil Texture and Hydraulic Properties

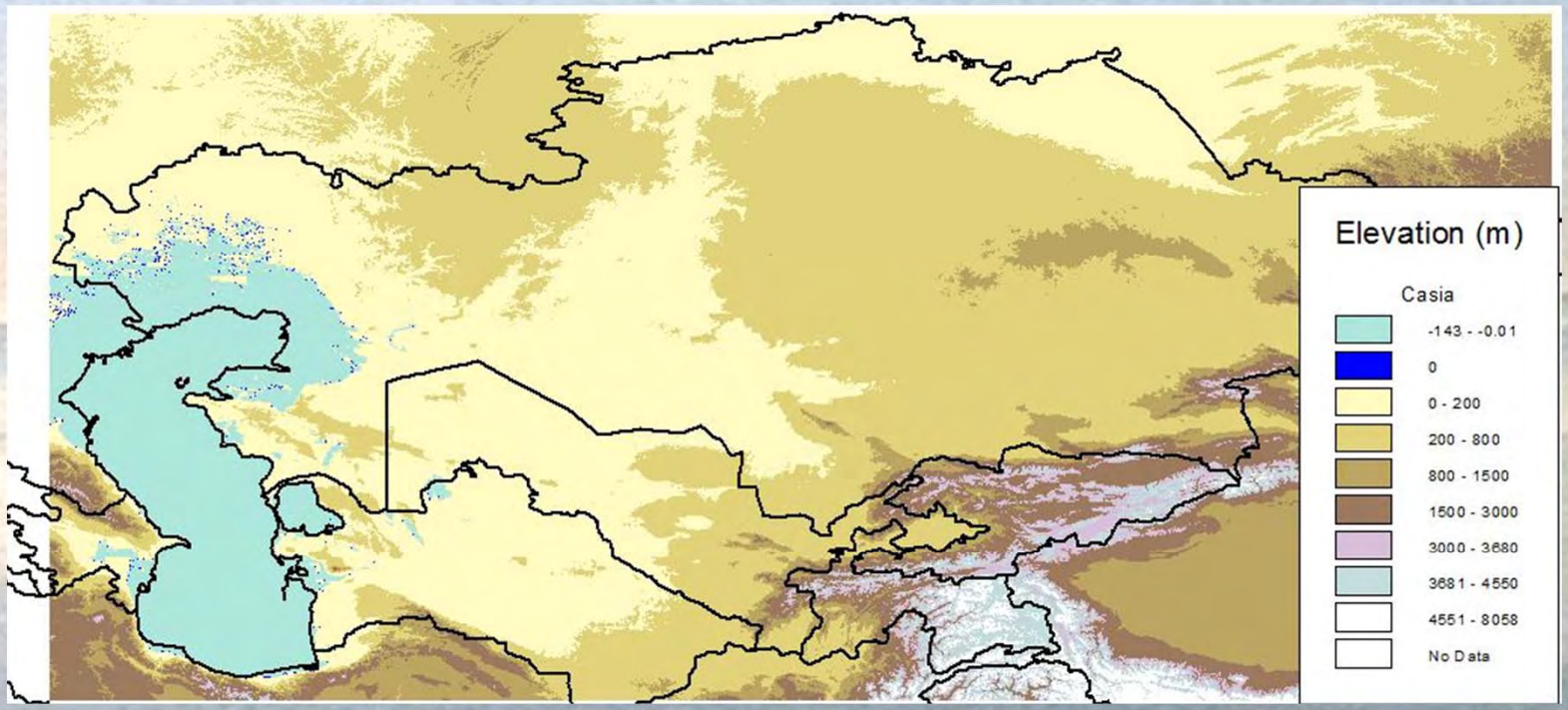
Soil Class	θ_r (m^3/m^3)	θ_s (m^3/m^3)	θ_m (m^3/m^3)	K_s (m/h)	α	σ_{ln} (m/h)
Sand	0.34	0.09	0.015	0.168	2.79	0.062
Loamy Sand	0.42	0.16	0.05	0.050	4.26	0.082
Sandy Loam	0.43	0.21	0.07	0.019	4.74	0.119
Loam	0.44	0.25	0.095	0.012	5.25	0.108
Silty Loam	0.48	0.29	0.11	0.010	5.33	0.090
Sandy Clay Loam	0.40	0.24	0.11	0.016	6.77	0.088
Clay Loam	0.47	0.32	0.17	0.009	8.17	0.099
Silty Clay Loam	0.46	0.33	0.19	0.007	8.72	0.103
Sandy Clay	0.41	0.29	0.18	0.026	10.73	0.054
Silty Clay	0.47	0.35	0.21	0.005	10.39	0.124
Clay	0.47	0.36	0.24	0.004	11.55	0.106

Values are from Clapp et al. 1984


SAC-SMA PARAMETERS
5.5 - 7
7 - 8.125
8.125 - 10
10 - 30
30 - 35
35 - 50
UZTM (mm)


SAC-SMA PARAMETERS
2.5 - 4.5
4.5 - 7.5
7.5 - 13.75
13.75 - 22.5
22.5 - 37.5
37.5 - 55
UZFM (mm)

GTOPO - Topography



Jensen-Haise:
PET - Radiation based method with 2 parameters

Pertinent Refernces:
Jensen & Haise 1963
McGuinness & Bordne 1973
Oudin et al 2005 j. Hydrology:

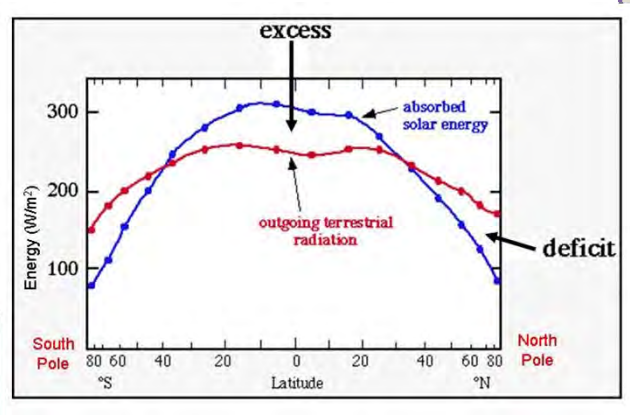
For basin scale hydrologic models, PET procedures that are based on extraterrestrial radiation and climatic surface temperature outperform complex models (e.g., Penman).

Potential Evaporation in a given location (mm/day):

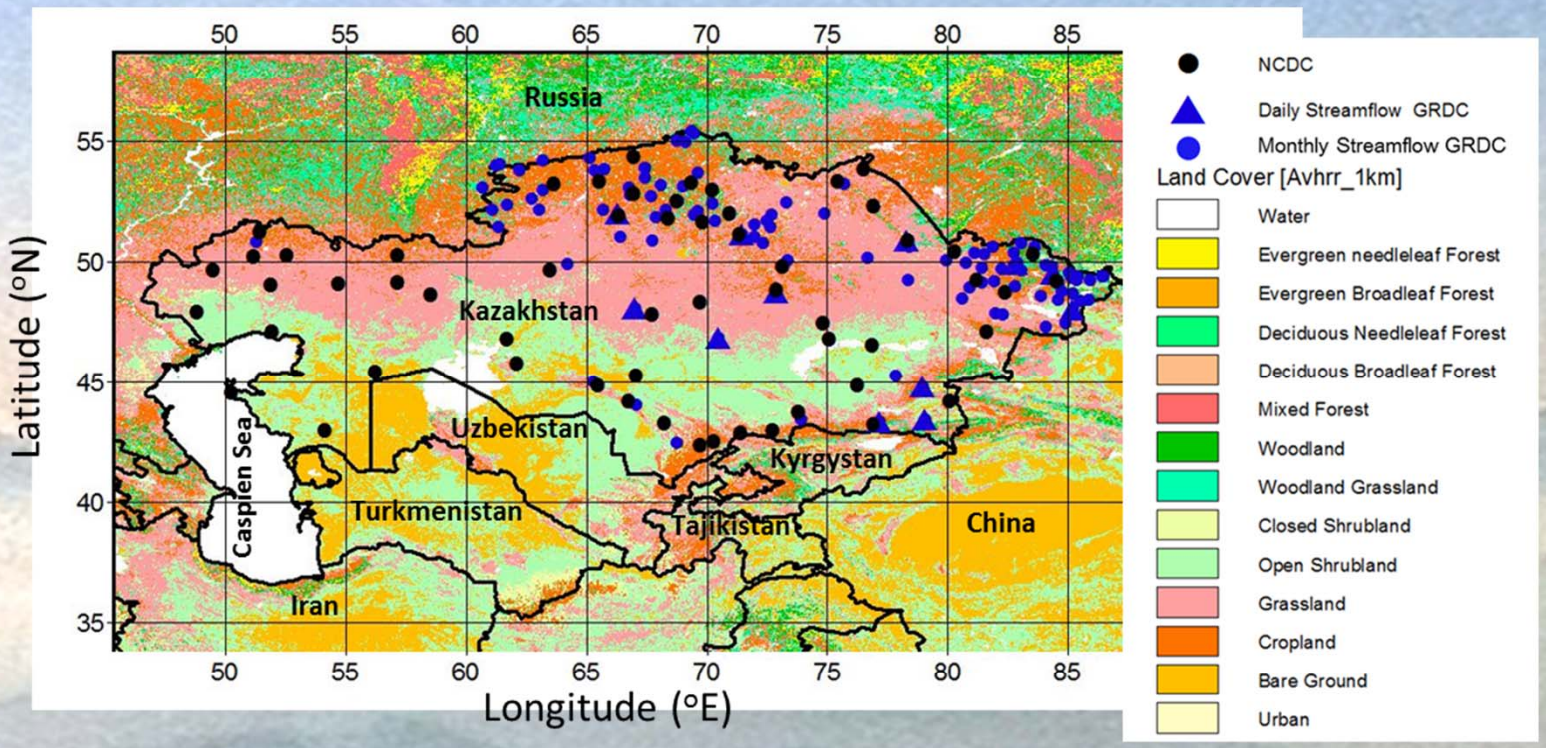
$$PE = [Re\ Ta + K2\ ] / K1(\lambda\ p)$$

for Ta > K2

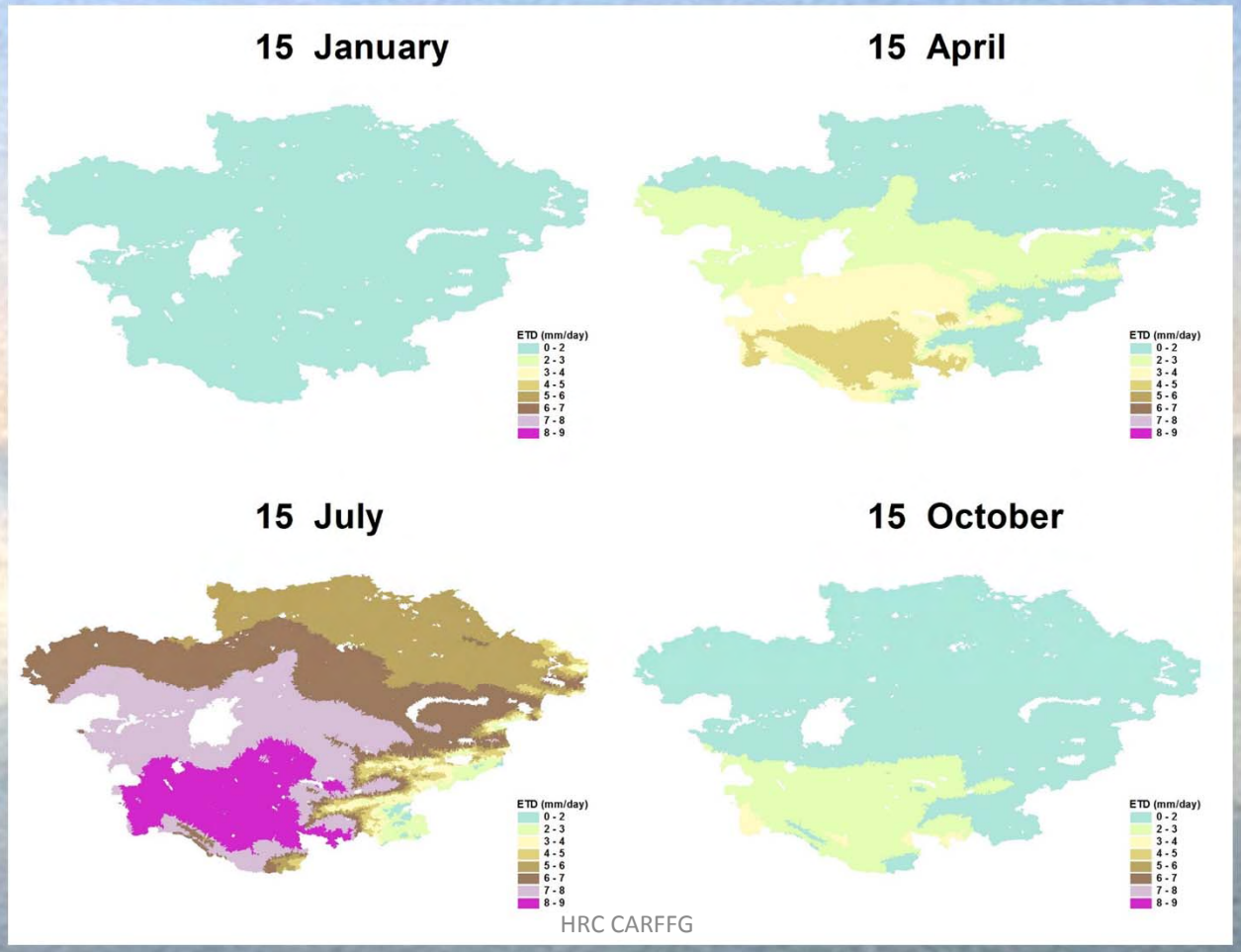
- **Re - Daily potential Incoming extraterrestrial radiation (Mj m^{-2} d^{-1});**
  - **f{latitude, Julian date)**
- **Ta- Long term daily averages of surface temperature (minT+maxT)/2**
  - **f{Julian date, elevation)**
- **K1 (°C) – minimum temperature in which below PE=0 (~5)**
- **K2 (°C) – scale parameter (75-130)**
- **λ – Latent heat flux (Mj kg^{-1})**
- ***p* - density of water (kg m^{-1})**

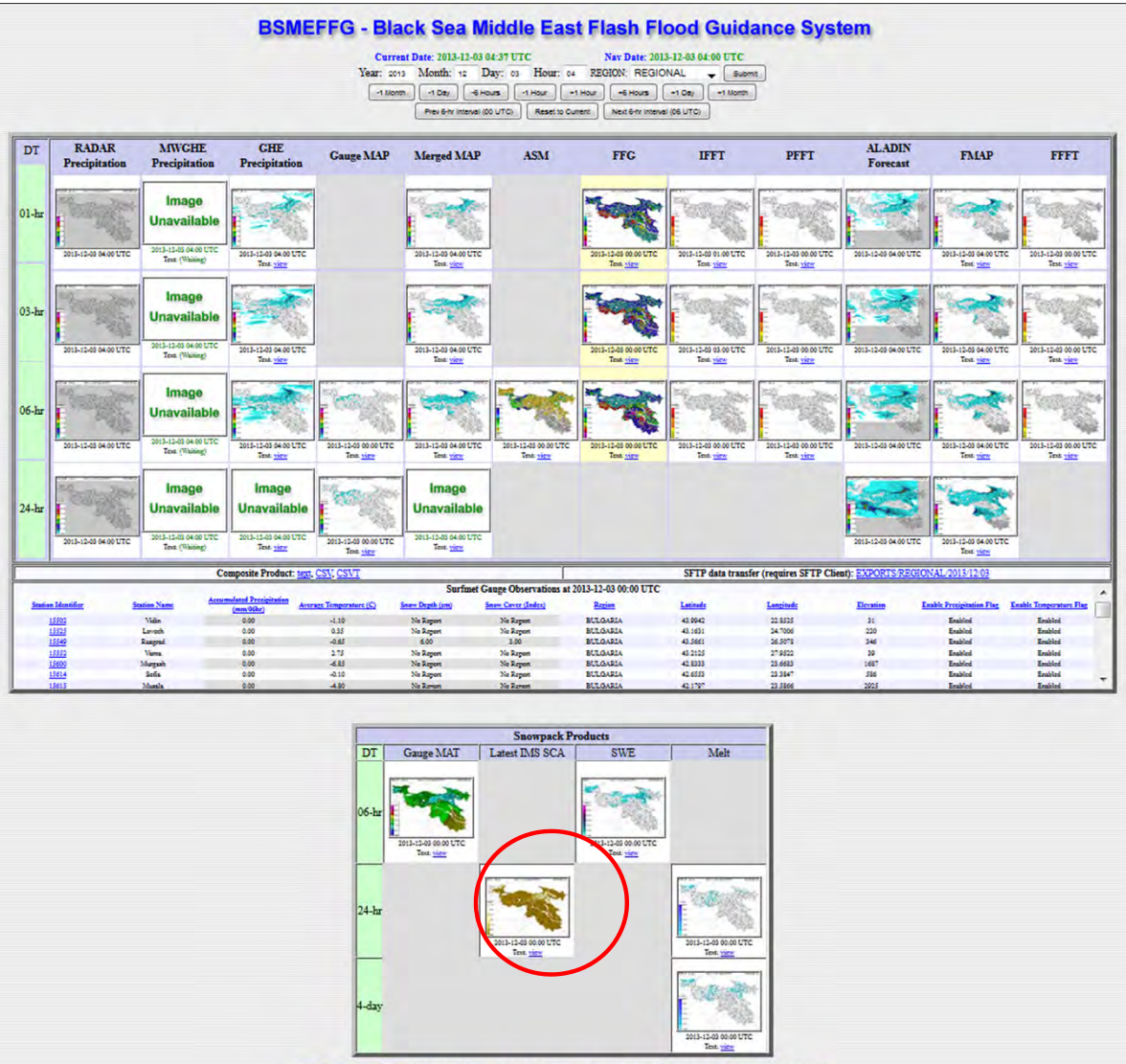


Kazakhstan Land Cover Map



PET Climatological Estimate

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DT
RADAR Precipitation
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Gauge MAP
Merged MAP
ASM
FFG
IFFT
PFFT
ALADIN Forecast
FMAP
FFFT
01-hr
03-hr
06-hr
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Snow Cover (Index)
Region
Latitude
Longitude
Elevation
Enable Precipitation Flag
Enable Temperature Flag
Snowpack Products
Gauge MAT
Latest IMS SCA
SWE
Melt
4-day
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BSMEFFG Real-Time Product Console v.1.0, Release Date: June 2013
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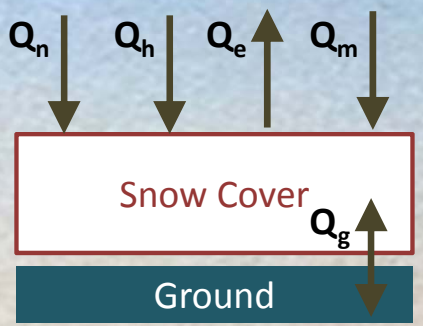
Snow Modeling

- Energy Balance for Snow Cover

$$Q_n + Q_e + Q_h + Q_g + Q_m = \Delta Q$$



where Q_n = net radiation (solar – longwave)
Q_e = latent heat transfer
Q_h = sensible heat transfer
Q_g = heat transfer at snow-soil interface
Q_m = heat transfer by mass changes (e.g. advected by rain)
ΔQ = change in heat storage of snow cover

$= f(Q_{sw}, Q_{lw}, A, T_o)$
$= f(e_o, u_a)$
$= f(T_o, T_a, u_a)$
$= f(T_g, T_s)$
$= f(p)$

Energy Balance solution is data intensive!

Snow Model - Snow 17

- ❑ Snow Accumulation and Ablation Model (SNOW-17) of the U.S. NWS (Anderson, 1973)
- ❑ Designed to use readily available operational data
- ❑ A conceptual areal lumped energy and mass balance model
- ❑ *Air Temperature* used as an index for pack energy and division of precipitation as rain or snow
- ❑ Considers: melt during no rain; melt during rain; no melt
- ❑ Model states track: snow water equivalent (SWE), heat deficit, pack temperature, liquid content.

- Single vertical layer
- Three modules:
- Melt during rain
- Melt during no rain
- Heat accounting during no melt

Describe the snow cover extent using the Snow Depletion Curve

Data Requirements

- Surface Air Temperature
  - Index for the pack energy balance and determine the form of precipitation (rain or snow)
- Precipitation
  - determine amount of snowfall and amount of rain-on-snow (PXTEMP)
  - SCF - Multiplying factor that adjusts precipitation data for gage catch deficiencies during periods of snowfall
- Other Data (when available)
  - Snowfall
  - Snow course and/or snow sensors (water-equivalent)
  - Areal extent of snow cover (satellite)

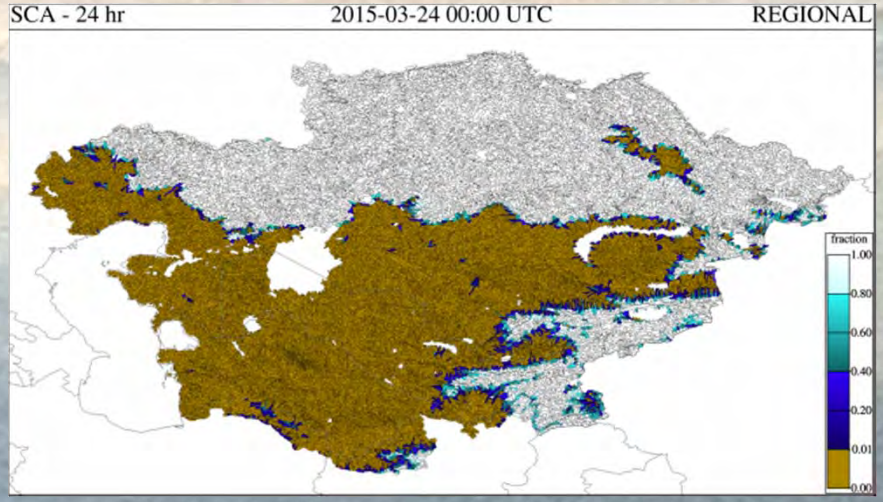
Satellite Snow Covered Area

- Interactive Multisensor Snow and Ice Mapping System (IMS), made available through National Snow and Ice Data Center, NOAA.
  http://nsidc.org/data/docs/noaa/g02156_ims_snow_ice_analysis/index.html
- Daily (23:00 GMT) snow cover based on summary of multiple satellites at 4km x 4km resolution.
  - Geostationary satellites
  - Polar orbiter: MODIS, AVHRR & Microwave
  - Assisted by modeling , climatological maps, and personnel expertise
- Generally available within 1 day (often within several hours) following date of observation
- 4km product is Operational since 2006
- **Helfrich et al., 2007 Hydrological Processes**

Use of Snow Cover in BSME

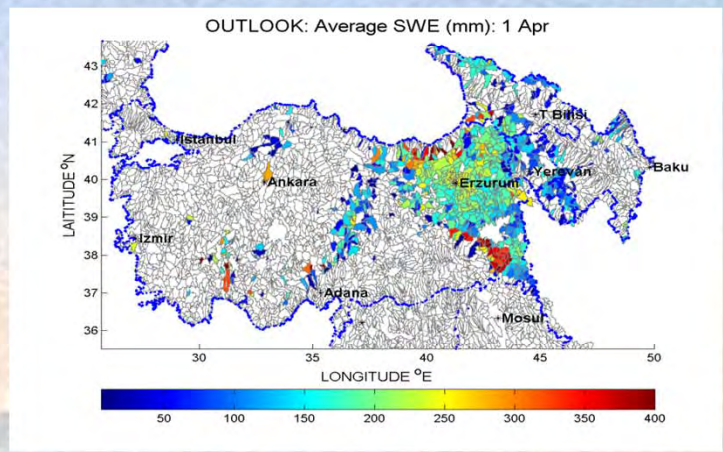
- Based on fraction of snow covered area in each subbasin
  - Aportion the rain for the uncovered areas
  - Soil-snow interface leakage at the snow cover areas
  - Rain for the FFT calculations is portioned to the uncovered areas

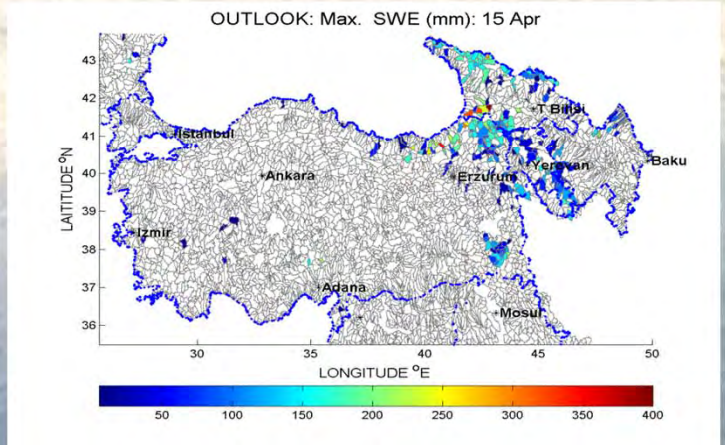
Sub-Basin Snow Cover Area Fraction



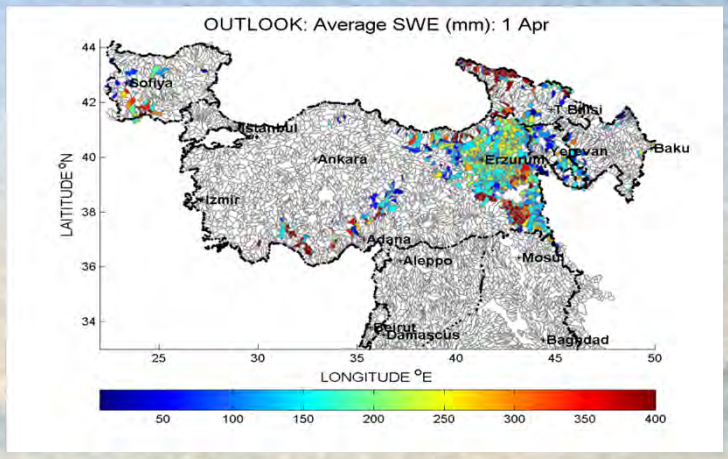
Comparison between April outlook for 2012 and 2013

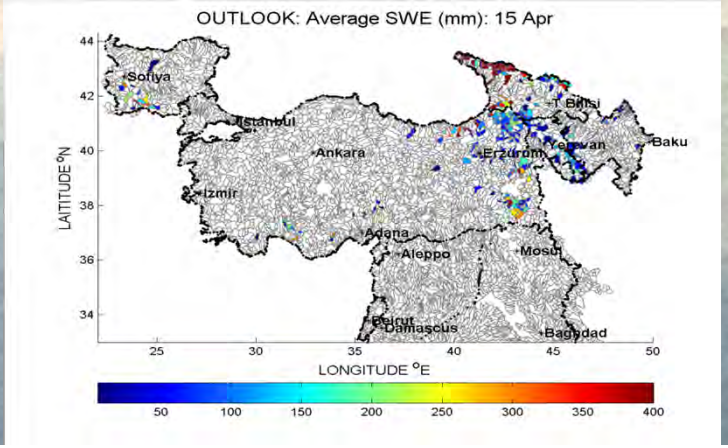
Outlook 2012



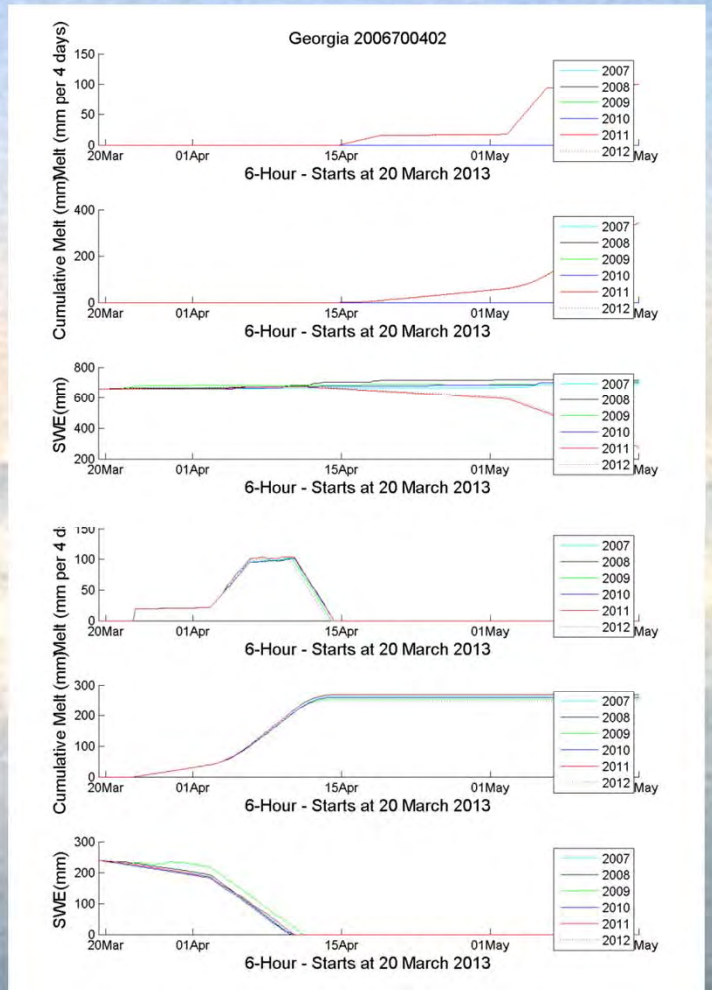


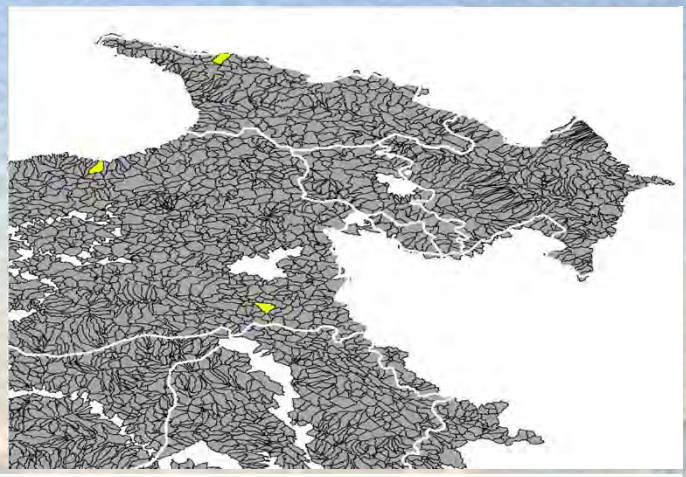
Outlook 2013

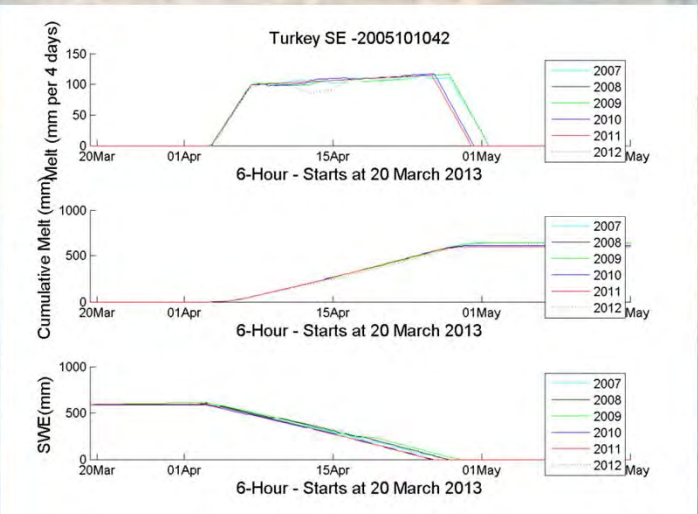




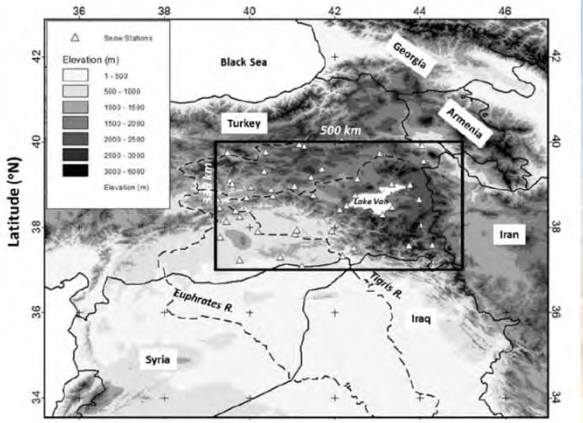
Time Series from Specific Basins

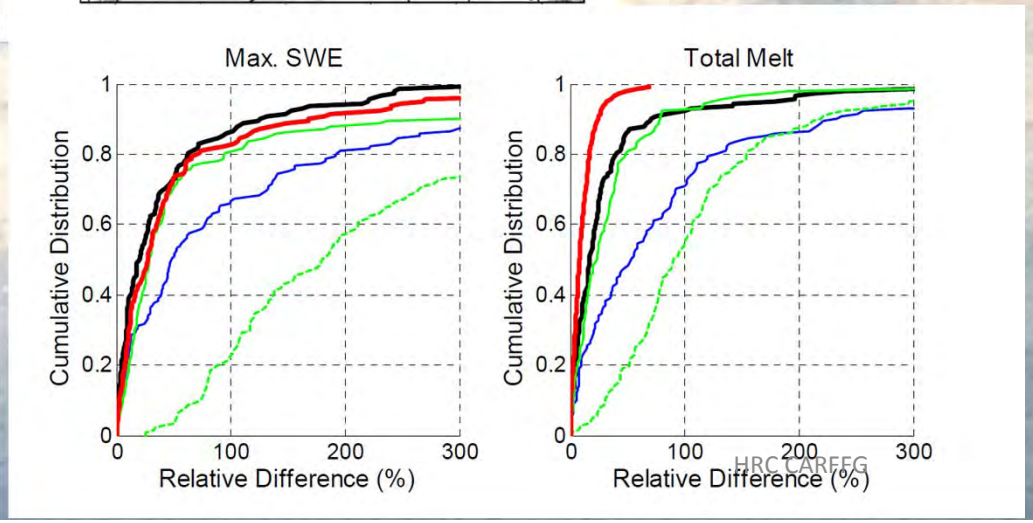






MODIS/LST for Surface Temperature [NASA funded Research]





INCORPORATING MODIS LAND SURFACE TEMPERATURE IN AN OPERATIONAL SNOW ACCUMULATION AND ABLATION MODEL

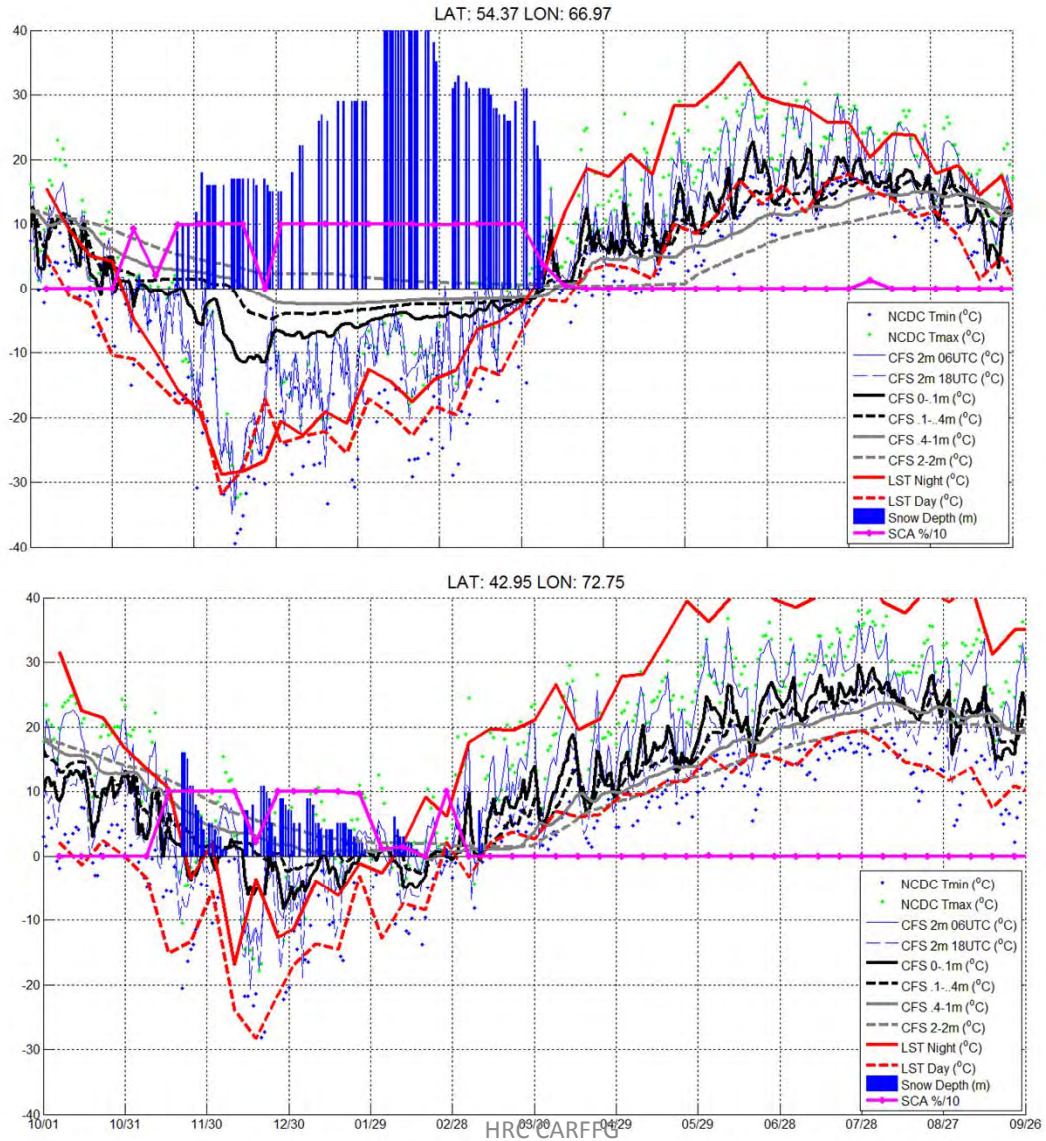
EYLON SHAMIR AND KONSTANTINE P. GEORGAKAKOS

HRC TECHNICAL NOTE NO. 55

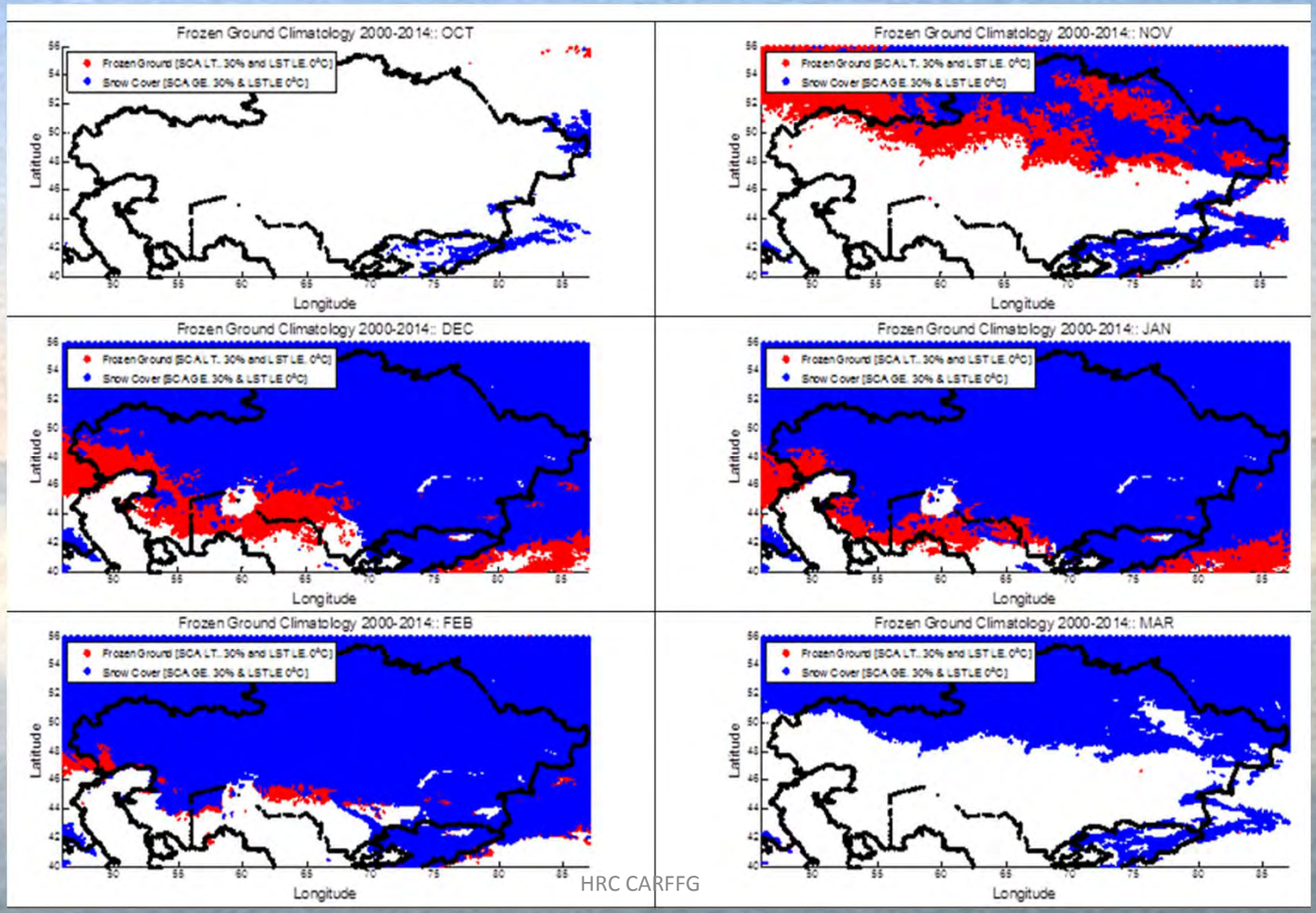
(Sponsored by NASA Grant No: NNX12AQ37G)

HYDROLOGIC RESEARCH CENTER
12555 High Bluff Drive, Suite 255, San Diego, CA 92130, USA

10 September 2013


LAT: 54.37 LON: 66.97
LAT: 42.95 LON: 72.75
NCDC Tmin (°C)
NCDC Tmax (°C)
CFS 2m 06UTC (°C)
CFS 2m 18UTC (°C)
CFS 0-.1m (°C)
CFS .1-..4m (°C)
CFS .4-1m (°C)
CFS 2-2m (°C)
LST Night (°C)
LST Day (°C)
Snow Depth (m)
SCA %/10
40
30
20
10
0
-10
-20
-30
-40
10/01
10/31
11/30
12/30
01/29
02/28
03/30
04/29
05/29
06/28
07/28
08/27
09/26

MODIS/Terra 8day LST vs. SCA 2000-2014



Theory of Threshold Runoff Estimation

Following Carpenter et al (1999), under a *linear response* of basins to rainfall excess, threshold runoff may be calculated under the following equality:

$$Q_p = q_{pR}\, R\, A \qquad (1)$$

Q_p is the flow associated with flooding flow (cms)

q_{pR} is the peak of the unit hydrograph of duration t_R, normalized by catchment area (cms/km^2/mm)

A is the catchment area (km^2)

R is t_R-hr threshold runoff (mm)

Theory of Threshold Runoff Estimation

Options to estimate parameters of threshold runoff (R):

(a) Flooding Flow, Q_p

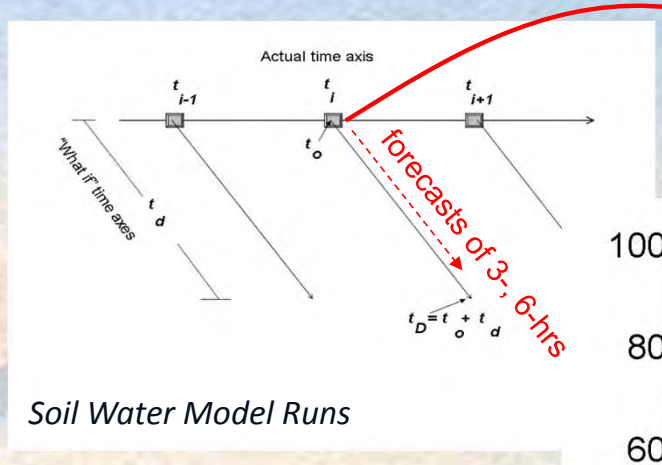
- Bankfull Flow (Manning's uniform flow; uses channel cross-section)
- Flow with given return period (statistical)

(b) Unit hydrograph response, q_{pR}

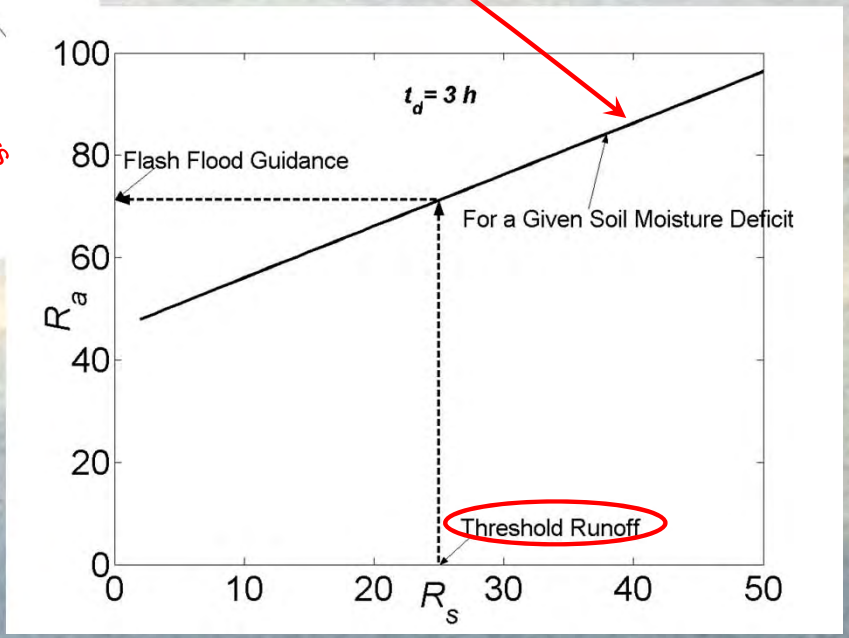
- Synthetic Unit Hydrograph (empirical)
- Geomorphologic Instantaneous Unit Hydrograph (physical properties)

$$R = f(A, L, B_b, D_b, S_c)$$

From Threshold Runoff and Soil Moisture to Flash Flood Guidance

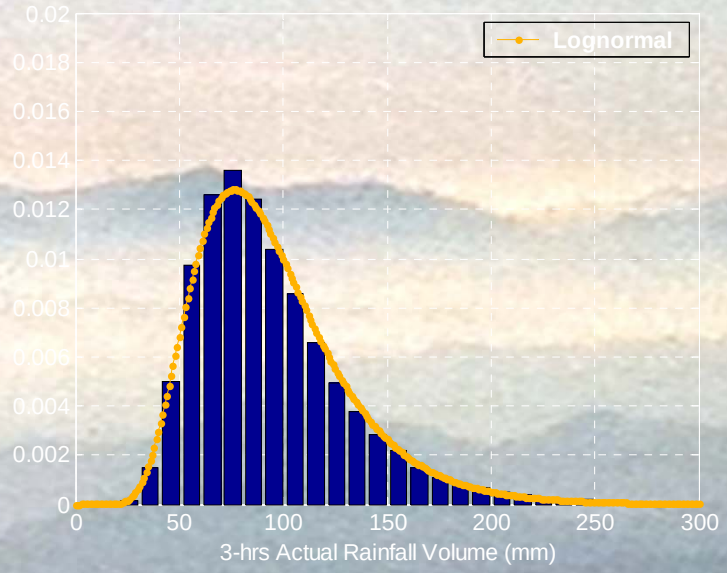


Soil Water Model Runs



FFG Uncertainty for Soil Wetness Conditions

Dry Conditions



Wet Conditions